SPACE EXPLORATION SYNTHETIC APERTURE RADAR - LUNAR INVESTIGATIONS TARGETED EXPERIMENT (SESAR-LITE)

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Abstract

The SESAR-LITE (Space Exploration Synthetic Aperture Radar - Lunar Investigations Targeted Experiment) instrument is a compact P-band (70 cm wavelength) polarimetric synthetic aperture radar under development at the NASA Goddard Space Flight Center (GSFC) to measure the surface and upper subsurface of the Moon at full polarimetry and at meter-scale resolution. The radar will use a compact deployable antenna, distributed RF electronics, and multi-channel digital processing system to enable a set of focused mission goals for small payload opportunities. The instrument development leverages proven technology advancements recently developed and demonstrated at NASA GSFC for SESAR (Space Exploration Synthetic Aperture Radar), a flagship version of the instrument that was tailored for larger orbital missions. The development of SESAR-LITE addresses accommodation flexibility on multiple launch vehicle families that require small packages while providing unprecedented surface and subsurface imaging of the Moon as required by NASA's Artemis program.

Index Terms— Radar, SAR, sounder, P-band, Moon, lunar, Artemis, subsurface, imaging, beamforming.

1. INTRODUCTION

SESAR-LITE is a P-band (435 MHz) orbital radar instrument capable of imaging up to several meters below the lunar surface at meter-scale spatial resolution and at full polarimetry. The radar measurements can reveal subsurface structure and stratigraphy of buried lunar features that address a number of scientific goals of NASA's Artemis program [1]. For example, these measurements can be used to characterize the physical properties of regolith and buried water ice and identify human-habitable regions of scientific interest, including lava tubes that can potentially serve as shelters for future human explorers.

The upper lunar subsurface region (upper 10 meters) is also close enough to the surface to be accessible to future human or robotic explorers. Therefore, characterizing the subsurface structure and mapping its stratigraphy will provide important context for understanding science and evaluating resources at lunar landing sites [2][3].

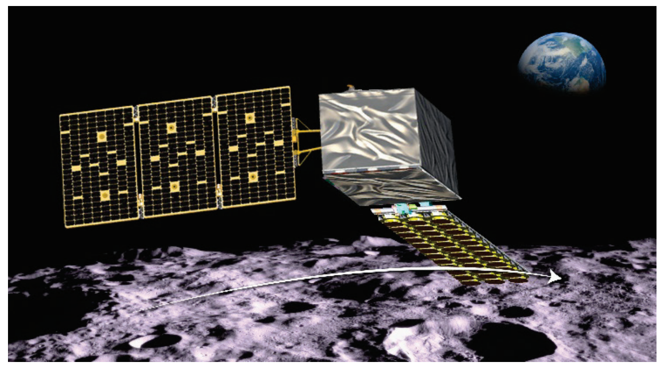

Fig. 1. SESAR-LITE's fully-polarimetric P-band (70 cm) signals penetrate several meters below the surface to detect subsurface features. Designed to fly on a smallsat, such as a NASA SIMPLEx mission, this radar can provide meter-scale spatial resolution imaging that addresses multiple Artemis, LEAG, and Decadal Survey science and exploration goals.

The SESAR-LITE radar instrument design employs a programmable beamforming architecture made up of "smart panels" that enable beam agile SAR imaging, sounding, or scatterometry, without slewing the antenna [3][4]. The architecture also permits selection of single (HH or VV), dual (HH, HV or VV,VH), full (HH,VV,VH,HV), or hybrid (transmit circular, receive H and V) polarizations depending on measurement requirements or data volume constraints.

In SAR imaging mode, SESAR-LITE would be capable of measuring the surface or subsurface over single or multiple beams at programmable incident angles to optimize geologic analysis. Each beam could measure up to four polarizations to facilitate retrieval of the Stokes parameters from which a broad suite of scattering mechanisms associated with particular geological processes can be assessed. Left- and right-of-the-track observations can provide imaging with increased coverage without degrading spatial resolution [5].

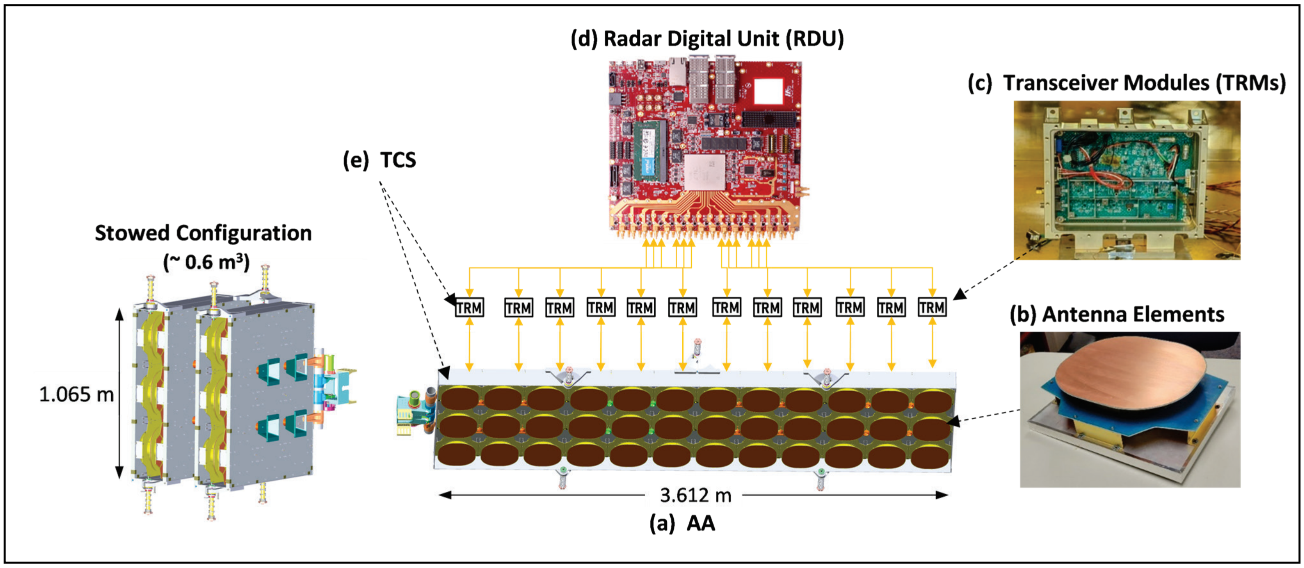

Fig. 2. SESAR-LITE's compact modular design employs four lightweight antenna panels and high efficiency distributed digital and RF electronics that enable low-cost lunar missions and compelling science.

In sounding mode, nadir observations would provide high resolution subsurface stratigraphy and the depths of the distinct subsurface layers, which combined with overlapping SAR observations can provide volumetric characterization of the lunar regolith. The scatterometry mode will help characterize the physical (e.g., roughness) and electrical (complex permittivity and loss tangent) properties of the surface and shallow subsurface at larger scales. Table 1 lists nominal performance parameters for SESAR-LITE's high resolution, full pol SAR imaging mode.

2. INSTRUMENT ARCHITECTURE

The SESAR-LITE development leverages state-of-the-art technology advancements recently developed and demonstrated (TRL 6) at NASA GSFC for SESAR [4], a flagship version of the instrument that was previously

Parameter	Value
Radar Orbit Altitude	41 km
Spacecraft Velocity	1,621 m/s
Look Angle (deg.)	45 deg
Center Frequency	435 MHz
Pulse Width	30 µs
Max Bandwidth	100 MHz
Polarization	HH, HV, VH, VV, LC, RC
Max. Slant Range Resolution	1.5 m
Single Look Azimuth Resolution	0.5 m
Single Look NESO	- 25 dB
PRF	6.4 kHz
Swath	20 km
Data Rate	583 Mbps
DC Ave. Power (W)	117 W

Table 1. SESAR-LITE's performance metrics for the SAR imaging mode.

designed for larger planetary missions (e.g., Mars orbit operation). In contrast, SESAR-LITE is being designed for compatibility with smallsat missions (e.g., NASA SIMPLEx type of missions). The instrument employs a modular and lightweight architecture that can be compactly stowed for launch and easily deployed for orbital operation (Fig. 2).

Similar to other previous NASA/GSFC radar designs [5], SESAR-LITE consists of an "active" Antenna Array made up of programmable radar panels (Fig. 2). Each radar panel consists of individually controlled subarrays which are commanded by a centralized FPGA-based Radar Digital Unit (RDU). The RDU generates and receives RF signals that are conditioned at each subarray by Transmit/Receive Modules (TRMs). The TRMs in turn direct and receive the signals from the antenna subarrays. A Thermal Control System (TCS) ensures the radar system components stay well within their specified operational and survival temperature ranges for the extreme temperature environment of a lunar orbit.

The SESAR-LITE Antenna Array (Fig. 2a) is made up of four antenna panels that are stowed and deployed by a custom hinge mechanism similar to the mechanisms used in solar arrays. Each antenna panel is populated with nine antenna elements (Fig. 2b) and three TRMs (Fig. 2c). The antenna elements were previously developed for SESAR [4][6] and were designed with composite materials to provide high stiffness and strength while having low mass (500 g each).

The SESAR-LITE TRMs also leverage transceiver technology previously designed, built and demonstrated (TRL 6) for SESAR [4]. The TRMs were designed for high power-efficiency and employed lightweight electronics. In this effort, pairs of the original SESAR TRMs design are being combined into a single printed circuit board (PCB) and enclosed by a single chassis to reduce instrument mass and

power consumption. The TRM circuits are also being optimized for higher performance and improved efficiency.

SESAR-LITE's RDU (Fig. 2d) employs two Xilinx Zynq UltraScale RF System on Chip (RFSoC) boards [7]. Each RFSoC board operates sixteen high-efficiency Digital-to-Analog (DAC) and Analog-to-Digital (ADC) converters within the FPGA. The RDUs will generate the radar transmit waveforms, acquire the radar signal returns from each subarray, perform onboard processing including beamforming and pulse compression. The RDU will also provide timing and control signals to the radar, and archive the collected data.

SESAR-LITE's TCS (Fig. 2e) is being designed to handle the worst-case temperature scenarios based on the solar β angle range for the expected lunar orbits. The TCS utilizes the chassis of the TRMs as heatsink/radiators, with conductive optical solar reflectors to minimize the thermal effects of solar impingement. A conductive thermal coating will be used on the front of the antenna. A multi-layer insulation (MLI) on the back of the ground plane will provide thermal isolation from the orbit environment. Preliminary worst hot case ($\beta = 0°$) and worst cold case ($\beta = 90°$) prediction models showed this approach would meet the instrument's operational and survival temperature requirements.

3. CONCLUSION

The SESAR-LITE instrument will enable a new class of surface and subsurface measurements of the Moon currently not available for lunar science or exploration. The instrument development is aimed at maturing the technology readiness level and demonstrating the unique features and capabilities of this radar in preparation for upcoming Artemis mission opportunities.

SESAR-LITEs full polarimetry, meter-scale resolution measurements, low power and lightweight design, and multimode operation will provide unprecedented information vital to future Moon orbital missions, and help pave the way for the next generation planetary radar systems.

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